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WIND-TUNNEL INVESTIGATION OF AILERON EFFECTIVENESS

OF 0.20-AIRFOIL-CHORD PLAIN AILERONS OF TRUE

AIRFOIL CONTOUR ON NACA 65_2-415, 65_3-418

AND 65_4-421 AIRFOIL SECTIONS

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NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

CONFIDENTIAL BULLETIN

WIND-TUNNEL INVESTIGATION OF AILERON EFFECTIVENESS OF 0.20-AIRFOIL-CHORD PLAIN AILERONS OF TRUE AIRFOIL CONTOUR ON NACA 65_2-415, 65_3-418 AND 65_4-421 AIRFOIL SECTIONS

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SUMMARY

An investigation was made in the NACA two-dimensional low-turbulence pressure tunnel to determine the aileron effectiveness of 0.20-airfoil-chord plain ailerons of true airfoil contour on the NACA 65_2-415, 65_3-418, and 65_4-421 airfoil sections. The aileron effectiveness parameter (change in section angle of attack with aileron deflection at constant lift coefficient) decreased very slightly with an increase in airfoil thickness from 15 percent to 21 percent. At higher deflections of the ailerons and higher section angles of attack, the increment of section lift coefficient due to aileron deflection was more appreciably reduced with an increase of airfoil thickness than was the aileron effectiveness parameter. The slope of the airfoil section lift curve c_{l_α} was substantially the same for the three airfoils tested.

INTRODUCTION

The use of low-drag airfoils has led to increased wing-tip thickness ratios for the purpose of improving the aerodynamic characteristics of the wing. Without causing much increase in drag, these larger tip thickness ratios of low-drag wings increase the low-drag range, improve stalling characteristics, and decrease a shift in span load distribution when compressibility conditions are encountered. This trend toward the use

of thicker outboard low-drag airfoil sections has led to the desirability of securing data regarding the effects of thick airfoils on aileron effectiveness.

The purpose of this investigation was to determine the aileron effectiveness of 0.20-airfoil-chord plain ailerons of true airfoil contour on the NACA 65_2-415, 65_3-418, and 65_4-421 low-drag airfoil sections. Tests have been made in the NACA two-dimensional low-turbulence pressure tunnel at a Reynolds number of approximately 6×10^6 and a Mach number less than 0.13. Lift measurements were made at aileron deflections through an approximate range from -20° to 20°.

SYMBOLS AND COEFFICIENTS

The symbols and coefficients used in the presentation of results are as follows:

α_o airfoil section angle of attack

c_l airfoil section lift coefficient

c airfoil chord

R Reynolds number

Δc_l c_l with aileron down minus c_l with aileron up

δ_a aileron deflection with respect to airfoil

$c_{l_\alpha} = (\partial c_l/\partial \alpha_o)_{\delta_a=0^\circ}$ (measured at $\alpha_o = 0^\circ$)

$c_{l_{\delta_a}} = (\partial c_l/\partial \delta_a)_{\alpha_o=0^\circ}$ (measured at $\delta_a = 0^\circ$)

$(\partial \alpha_o/\partial \delta_a)_{c_l}$ aileron effectiveness parameter $\left(c_{l_{\delta_a}}/c_{l_\alpha}\right)$

DESCRIPTION OF MODELS AND TEST METHODS

The three models, of 24-inch chord, were constructed at the Langley Memorial Aeronautical Laboratory and had

NACA 65_2-415, 65_3-418, and 65_4-421 airfoil sections; the ordinates of these airfoil sections are presented in tables I to III. The models were constructed of laminated mahogany, painted with lacquer primer surfacer and sanded smooth, and were equipped with 0.20c plain ailerons of true airfoil contour made of solid dural to minimize spanwise deflections of the aileron under load. The aileron gaps were sealed with modeling clay for all tests. Drawings of the ailerons are presented in figure 1.

The models spanned the rectangular test section, and section lift coefficients were obtained with a manometer arrangement that integrated the lift reaction of the model on the floor and the ceiling of the wind tunnel. Section lift coefficients and angles of attack were corrected for tunnel-wall effects according to the following formulas:

$$c_l = \left[1 - 2\beta(\gamma + \sigma) - \gamma\right] c_l'$$

$$\alpha_o = (1 + \gamma)\,\alpha_o'$$

where

c_l' airfoil section lift coefficient measured in tunnel

α_o' airfoil section angle of attack with respect to free-stream tunnel air

β factor dependent on airfoil shape

γ factor dependent on ratio of airfoil chord to tunnel height

σ factor allowing for interference of model on static-plate pressure; dependent on size and location of model

The values of $1 - 2\beta(\gamma + \sigma) - \gamma$ were 0.975, 0.973, and 0.971 for the NACA 65_2-415, 65_3-418, and 65_4-421 airfoil sections, respectively. The quantity $1 + \gamma$ was equal to 1.015 for all three airfoils.

RESULTS AND DISCUSSION

Plain-airfoil section characteristics of the three airfoils tested are given in reference 1. The section lift coefficients presented herein may differ slightly from those in reference 1 as a result of improved correction factors used for the present calculations.

Aileron effectiveness is measured by the change in section angle of attack per unit aileron deflection at a constant c_l. The value of this parameter varies with aileron deflection and usually becomes smaller with larger deflections. As the aileron deflection is decreased, the effectiveness approaches a limiting value equal to $c_{l_{\delta_a}}/c_{l_\alpha}$ or $(\partial\alpha_0/\partial\delta_a)_{c_l}$, which is used herein for purposes of comparison.

Lift characteristics of the airfoil sections tested are presented in figures 2 to 4 for several aileron deflections approximately from -20° to 20°. The variations of $c_{l_{\delta_a}}$, c_{l_α}, and $(\partial\alpha_0/\partial\delta_a)_{c_l}$ with airfoil thickness are presented in figure 5. The value of c_{l_α} for the three airfoils tested remained substantially constant; the values ranged from 0.112 for the 15-percent-thick airfoil to 0.111 for the 21-percent-thick airfoil. The value of $(\partial\alpha_0/\partial\delta_a)_{c_l}$ decreased very slightly from 0.479 for the 15-percent-thick airfoil to 0.466 for the 21-percent-thick airfoil. The average value of $(\partial\alpha_0/\partial\delta_a)_{c_l}$ for the three airfoils tested is approximately 86 percent of the value predicted from thin-airfoil theory (reference 3) and is 5 percent greater than the value obtained on the NACA 0009 airfoil as presented in reference 2 (also shown in fig. 5).

A more pronounced effect of airfoil thickness on aileron effectiveness occurs at the higher aileron deflections and section angles of attack at which the air flow over the aileron has separated. At the higher section angles of attack, the increment of section lift coefficient due to total aileron deflections of ±10°, ±15°, and ±20° decreases with an increase of airfoil thickness as shown by the curves of Δc_l plotted against α_0 in figures 6 to 8. For a total aileron deflection

of ±15° at a section angle of attack of 12° (fig. 7), the Δc_l available for the 15-, 18-, and 21-percent-thick airfoils is about 56.3, 50.3, and 44.5 percent, respectively, of the theoretical value of Δc_l. The theoretical value of Δc_l was calculated by using thin-airfoil values of $2\pi/57.3$ for the lift-curve slope c_{l_α} and 0.55 for $(\partial \alpha_0/\partial \delta_a)_{c_l}$ obtained from reference 3.

CONCLUDING REMARKS

The aileron effectiveness parameter (change in section angle of attack with aileron deflection at constant lift coefficient) decreased very slightly with an increase in airfoil thickness from 15 percent to 21 percent for the NACA 65_2-415, 65_3-418, and 65_4-421 airfoil sections. At higher deflections of the 0.20-airfoil-chord ailerons and higher section angles of attack, the increment of section lift coefficient due to aileron deflection was more appreciably reduced with an increase of airfoil thickness than was the aileron effectiveness parameter. The slope of the airfoil section lift curve c_{l_α} was substantially the same for the three airfoils tested.

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1. Jacobs, Eastman N., Abbott, Ira H., and Davidson, Milton: Preliminary Low-Drag-Airfoil and Flap Data from Tests at Large Reynolds Numbers and Low Turbulence, and Supplement. NACA ACR, March 1942.

2. Ames, Milton B., Jr., and Sears, Richard I.: Determination of Control-Surface Characteristics from NACA Plain-Flap and Tab Data. NACA Rep. No. 721, 1941.

3. Glauert, H.: Theoretical Relationships for an Aerofoil with Hinged Flap. R. & M. No. 1095, British A.R.C., 1927.

TABLE I.- NACA 65_2-415 AIRFOIL

[Stations and ordinates given in percent of airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.312	1.216	.688	-1.016
.541	1.481	.959	-1.201
1.017	1.893	1.483	-1.465
2.231	2.677	2.769	-1.933
4.697	3.865	5.303	-2.601
7.184	4.795	7.816	-3.099
9.682	5.575	10.318	-3.507
14.697	6.841	15.303	-4.149
19.726	7.807	20.274	-4.623
24.764	8.547	25.236	-4.967
29.807	9.090	30.193	-5.202
34.854	9.453	35.146	-5.333
39.903	9.637	40.097	-5.353
44.953	9.617	45.047	-5.237
50.000	9.371	50.000	-4.957
55.043	8.908	54.957	-4.528
60.079	8.257	59.921	-3.973
65.106	7.458	64.894	-3.338
70.124	6.540	69.876	-2.652
75.131	5.530	74.869	-1.950
80.126	4.447	79.874	-1.263
85.109	3.320	84.891	-.628
90.080	2.175	89.920	-.107
95.040	1.057	94.960	.207
100	0	100	0
L.E. radius: 1.505 Slope of radius through L.E.: 0.168			

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TABLE II.- NACA 65_3-418 AIRFOIL

[Stations and ordinates given in percent of airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.278	1.418	.722	-1.218
.503	1.729	.997	-1.449
.973	2.209	1.527	-1.781
2.181	3.104	2.819	-2.360
4.639	4.481	5.361	-3.217
7.123	5.566	7.877	-3.870
9.619	6.478	10.381	-4.410
14.636	7.942	15.364	-5.250
19.671	9.061	20.329	-5.877
24.716	9.914	25.284	-6.334
29.768	10.536	30.232	-6.648
34.825	10.944	35.175	-6.824
39.884	11.140	40.116	-6.856
44.943	11.091	45.057	-6.711
50.000	10.774	50.000	-6.362
55.051	10.198	54.949	-5.818
60.094	9.408	59.906	-5.124
65.126	8.454	64.874	-4.334
70.146	7.368	69.854	-3.480
75.154	6.183	74.846	-2.603
80.147	4.927	79.853	-1.743
85.127	3.638	84.873	-.946
90.092	2.350	89.908	-.282
95.046	1.120	94.954	.144
100	0	100	0

L.E. radius: 1.96
Slope of radius through L.E.: 0.168

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TABLE III.- NACA 65_4-421 AIRFOIL

[Stations and ordinates given in percent of airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.246	1.609	.754	-1.409
.468	1.950	1.032	-1.670
.935	2.482	1.565	-2.054
2.134	3.507	2.866	-2.763
4.583	5.079	5.417	-3.815
7.062	6.328	7.938	-4.632
9.557	7.362	10.443	-5.294
14.576	9.031	15.424	-6.339
19.616	10.300	20.384	-7.116
24.668	11.267	25.332	-7.687
29.729	11.972	30.271	-8.084
34.796	12.433	35.204	-8.313
39.865	12.640	40.135	-8.356
44.934	12.549	45.066	-8.169
50.000	12.145	50.000	-7.733
55.059	11.456	54.941	-7.076
60.108	10.525	59.892	-6.241
65.145	9.470	64.855	-5.290
70.168	8.157	69.832	-4.269
75.175	6.802	74.825	-3.222
80.167	5.381	79.833	-2.197
85.143	3.937	84.857	-1.245
90.103	2.511	89.897	-.443
95.051	1.176	94.949	.088
100	0	100	0
L.E. radius: 2.50 Slope of radius through L.E.: 0.168			

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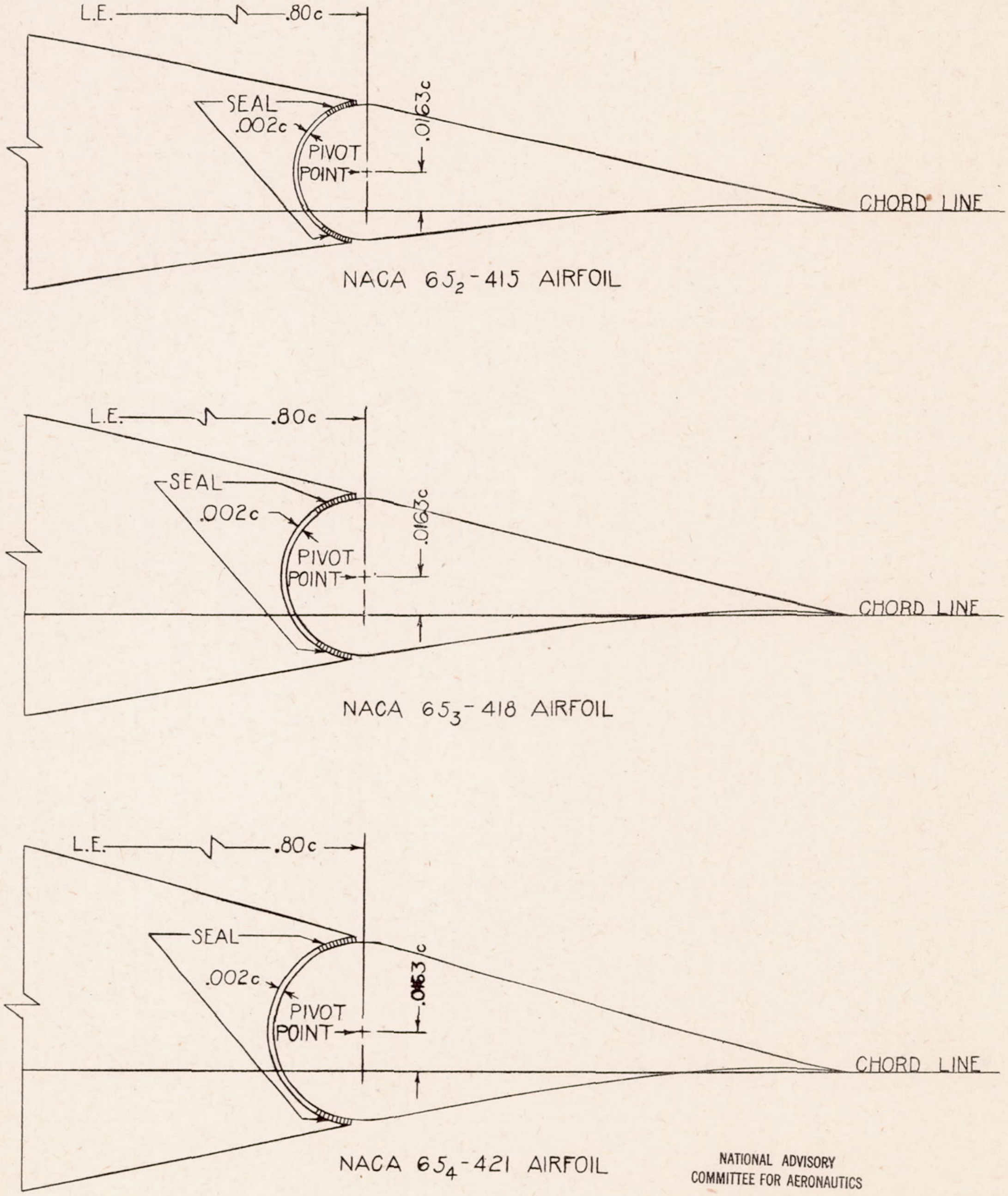

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Figure 1.- Sealed-gap 0.20c plain ailerons of true airfoil contour on NACA 65_2-415, 65_3-418, and 65_4-421 airfoil sections.

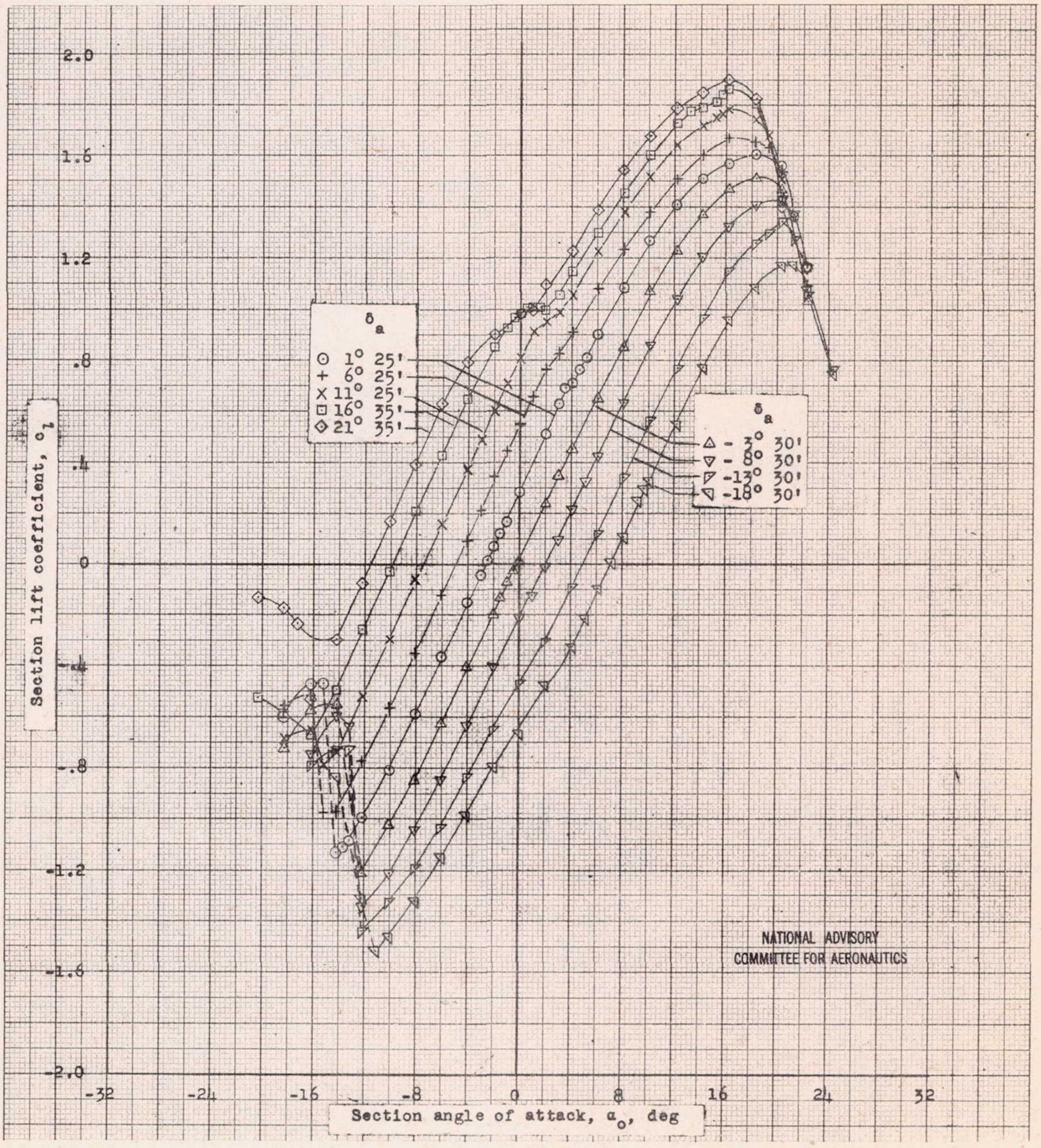

Figure 2.- Lift characteristics of an NACA 65_2-415 airfoil section equipped with sealed-gap 0.20c plain aileron of true airfoil contour; R, 6 x 10^6 (approx.); test, TDT 605.

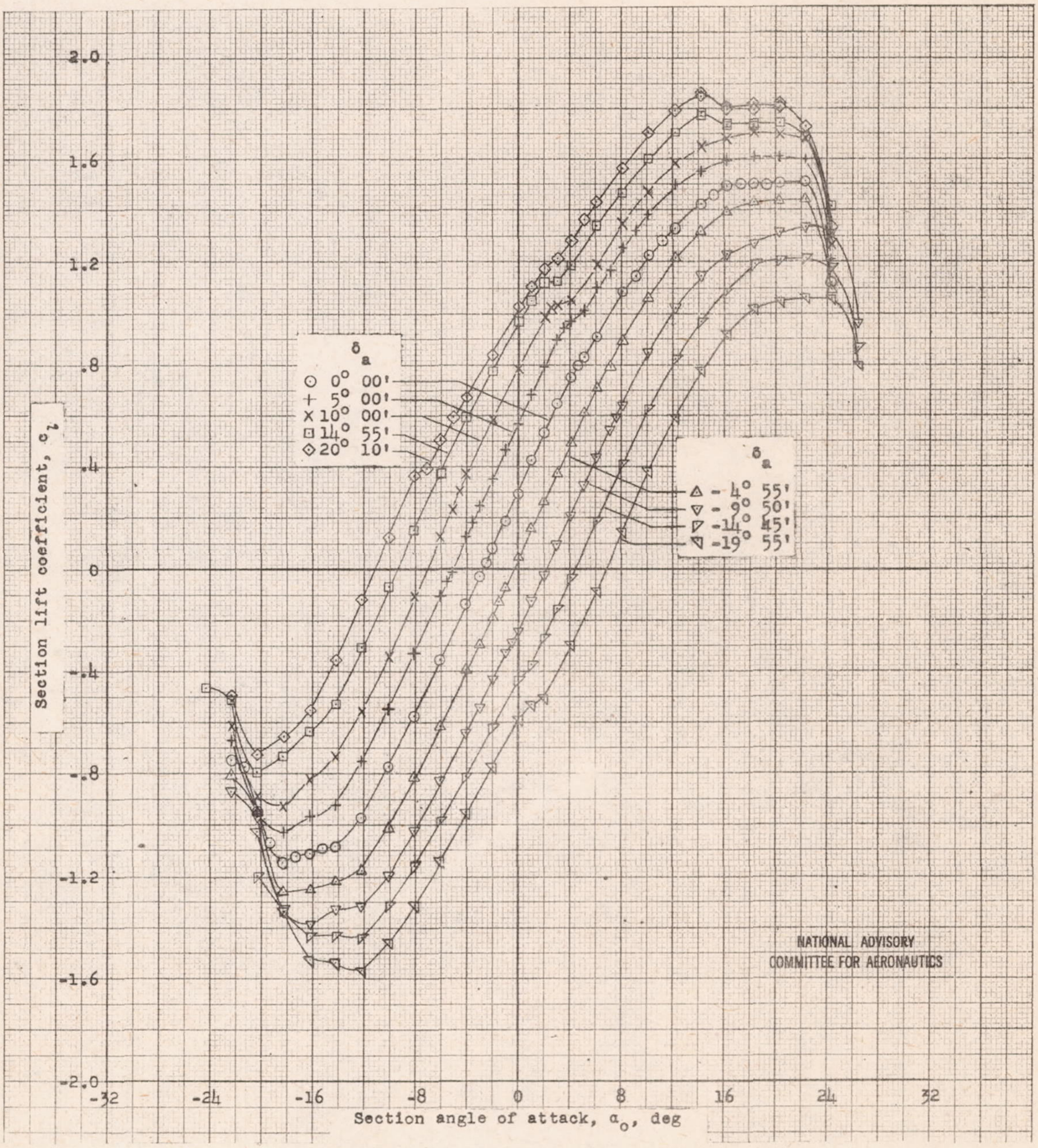

Figure 3.- Lift characteristics of an NACA 65_3-418 airfoil section equipped with sealed-gap 0.20c plain aileron of true airfoil contour; R. 6×10^6 (approx.); test, TDT 629.

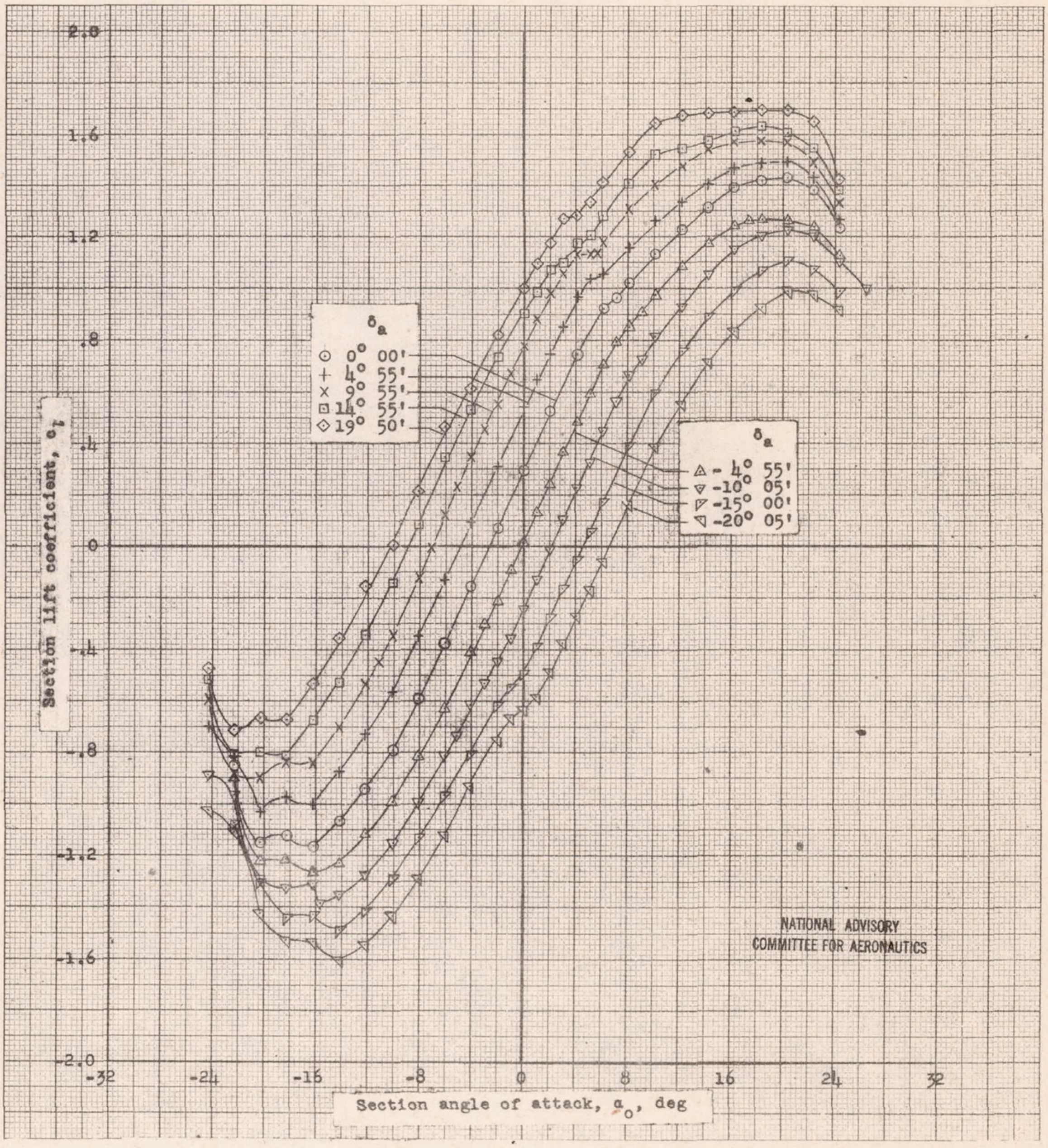

Figure 4.- Lift characteristics of an NACA 65_4-421 airfoil section equipped with sealed-gap 0.20c plain aileron of true airfoil contour; R, 6×10^6 (approx.); test, TDT 615.

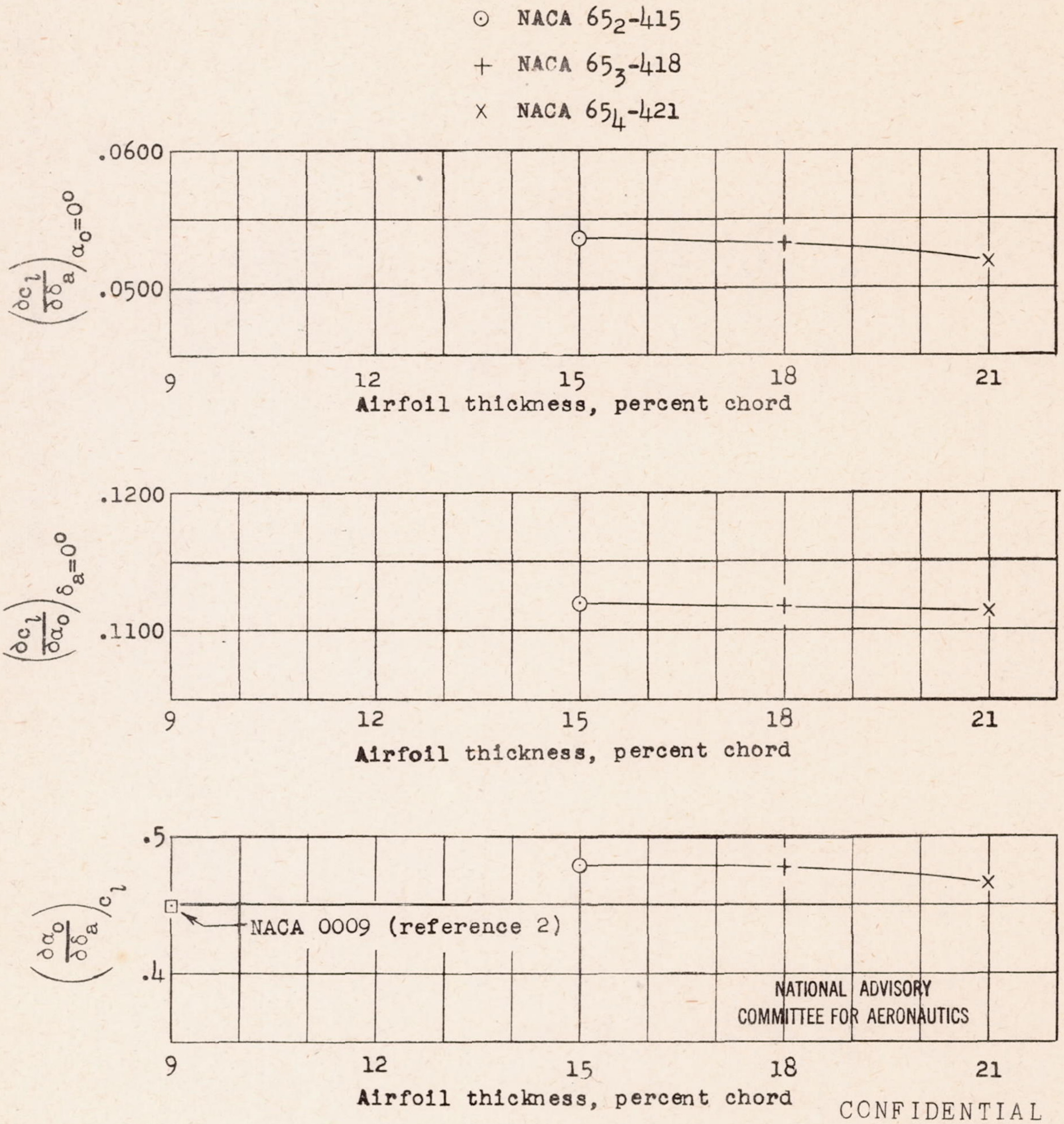

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Figure 5.- Variation of $\left(\frac{\partial c_l}{\partial \delta_a}\right)_{\alpha_o=0^\circ}$, $\left(\frac{\partial c_l}{\partial \alpha_o}\right)_{\delta_a=0^\circ}$, and $\left(\frac{\partial \alpha_o}{\partial \delta_a}\right)_{c_l}$ with airfoil thickness for NACA 65_2-415, 65_3-418, and 65_4-421 airfoil sections equipped with sealed-gap 0.20c plain ailerons of true airfoil contour; R, 6×10^6 (approx.).

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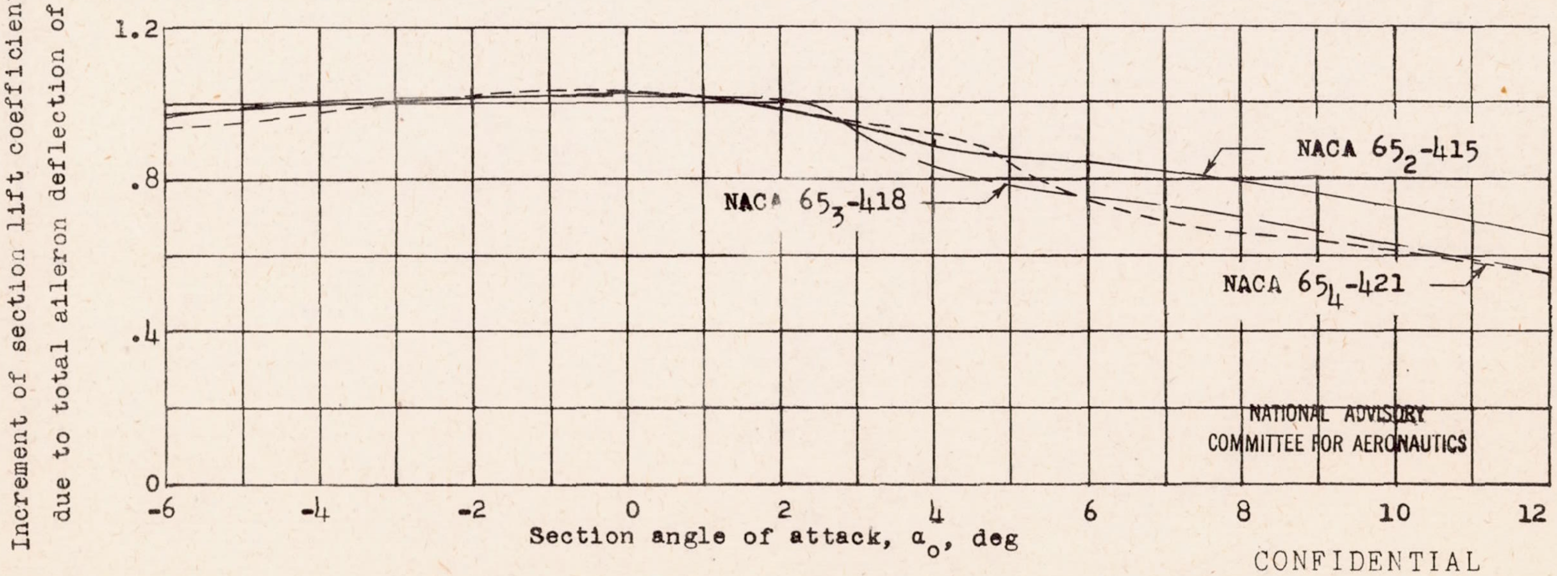

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Figure 6.- Variation of Δc_l with α_o for NACA 65_2-415, 65_3-418, and 65_4-421 airfoil sections equipped with sealed-gap 0.20c plain ailerons of true airfoil contour; R, 6×10^6 (approx.).

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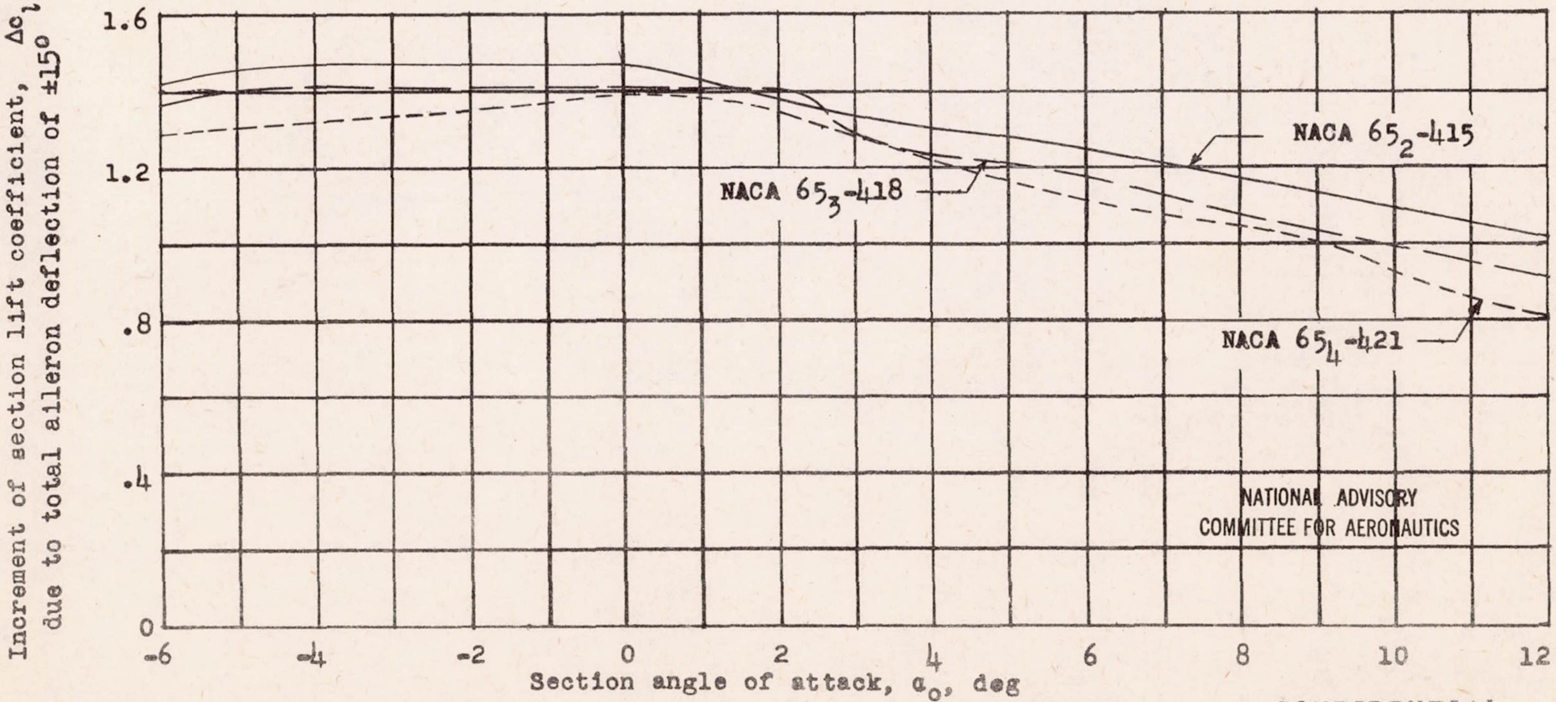

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Figure 7.- Variation of Δc_l with α_o for NACA 65_2-415, 65_3-418, and 65_4-421 airfoil sections equipped with sealed-gap 0.20c plain ailerons of true airfoil contour; R, 6×10^6 (approx.).

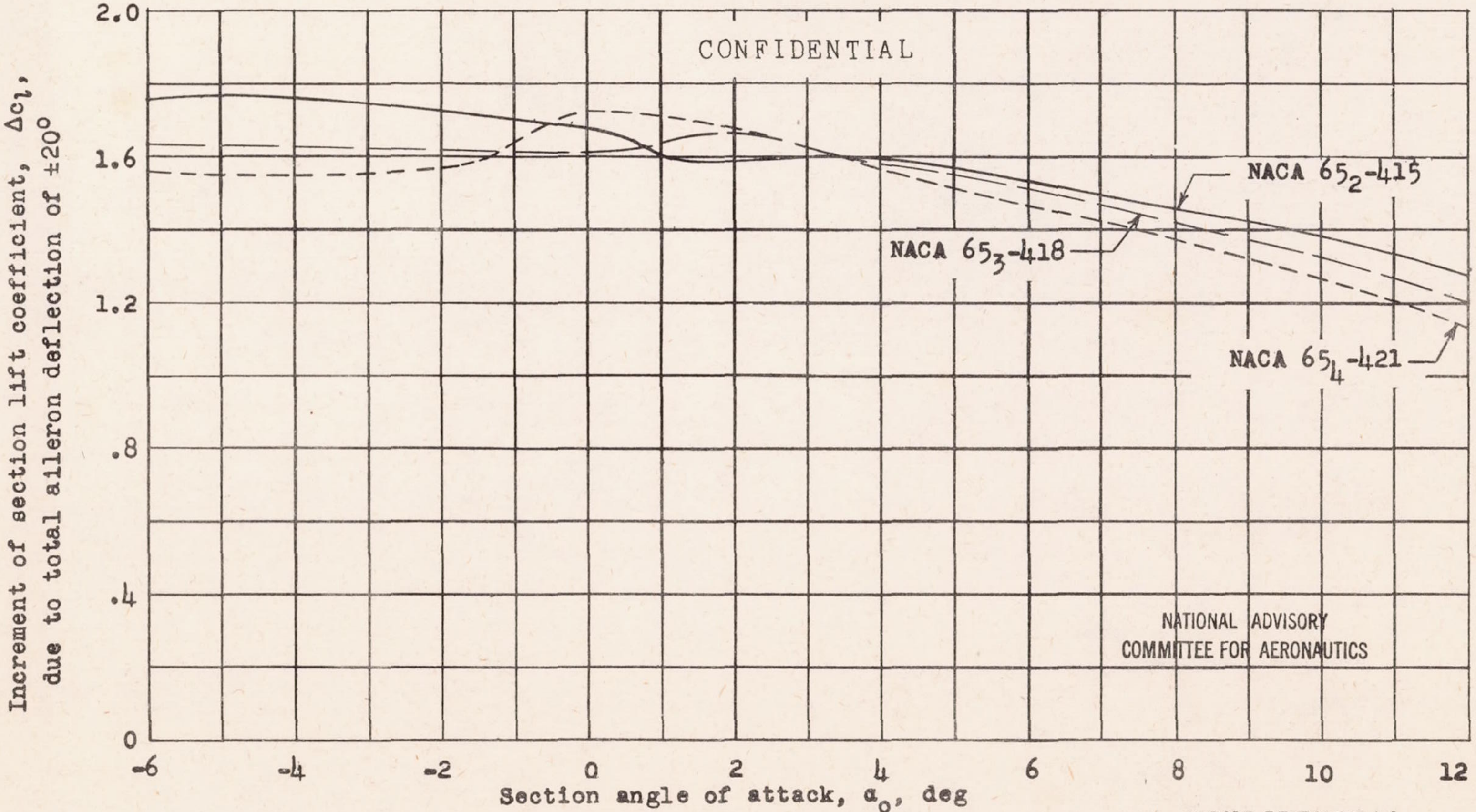

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Figure 8.- Variation of Δc_l with α_o for NACA 65_2-415, 65_3-418, and 65_4-421 airfoil sections equipped with sealed-gap 0.20c plain ailerons of true airfoil contour; R, 6×10^6 (approx.).